

The University of Chicago

THE RELATIVE INFLUENCE OF ACCOMMODATION AND CONVERGENCE IN THE JUDGMENT OF DISTANCE

A DISSERTATION SUBMITTED TO THE
GRADUATE FACULTY IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PSYCHOLOGY

By
HAROLD A. SWENSON

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THE RELATIVE INFLUENCE OF ACCOMMODATION AND CONVERGENCE IN THE JUDGMENT OF DISTANCE*

From the Psychological Laboratories of the University of Chicago

H. A. SWENSON

STATEMENT OF PROBLEM

It is generally admitted that judgments of the distance of visual objects are based to a considerable extent upon the associated processes of convergence and accommodation. The present study is an attempt to evaluate in quantitative terms the relative influence of these two factors in the judgment of distance.

HISTORICAL

The problem is one of many years standing, but it remains unsolved in spite of a considerable amount of experimentation. This failure is due to the inadequacy of the apparatus and methods employed.

The experiments in this field fall under two general headings:

1. Comparisons of monocular and binocular judgments.
2. Dissociation of accommodation and convergence.
 - a. Dissociation due to inability to accommodate.
 - b. Dissociation due to voluntary control of accommodation.
 - c. Stereoscopic dissociation.
 - 1) Free stereoscopy.
 - 2) Instrumental stereoscopy.

1. The first, or so-called classical method, involves a comparison of the relative accuracy of monocular and binocular judgments of distance. It was employed by Wundt (17), Hillebrand (8), Dixon (7), and Arrer (1), for example. These experimenters attempted to eliminate the influence of all secondary criteria by instrumental means. In general, it was assumed that both convergence and accommodation were present in the binocular adjustments, while only accommodation was operative in the monocular estimations. These experimenters found that the distance of objects could be estimated

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with some degree of accuracy with monocular vision, but that binocular judgments were the more accurate. They concluded that accommodation was effective in so far as accurate judgments were made with monocular vision, and that the convergent factor was responsible for the greater accuracy of the binocular judgments.

The exclusion of all secondary criteria in the classical experiments may be seriously questioned. Furthermore, most of them involve one fatal defect—the fallacious assumption that convergent changes are not present in monocular adjustments to the distance of objects. The presence of convergence in monocular vision is readily observable when vision of the one eye is excluded either by lid closure or by means of a screen. The fallacious character of the assumption was early noted by Arrer (1) and by Judd (12, p. 226), and it was again emphasized by Baird (3) in his admirable critical summary of this literature. The fallacy of the assumption is now generally admitted. Convergence and accommodation are present in monocular as well as in binocular vision. If all secondary criteria are excluded, the ability to judge the distance of objects with monocular vision is mediated by convergence as well as by accommodation, and the greater accuracy of binocular judgments is based upon some other factor—presumably binocular parallax. Obviously, these experiments give no information as to the *relative* effectiveness of accommodation and convergence.

Baird's experiment was modeled after that of Hillebrand. He constructed and employed an improved form of the Hillebrand apparatus and secured and tabulated the data for five subjects for the following five conditions: (1) monocular abrupt series, (2) binocular abrupt series, (3) monocular gradual series, (4) monocular estimation of absolute distance, and (5) binocular estimation of absolute distance.

Baird did not use this tabular data as to the relative accuracy of monocular and binocular judgments in his conclusions concerning the relative influence of convergence and accommodation. As we have already noted, Baird seriously criticized the assumptions of this method in the historical introduction of his paper.

From these circumstances, one may venture the surmise that Baird planned and conducted his experiment in accordance with the classical method, but discovered the fallacy involved in this method during the course of his experiments. This surmise is further supported by the fact that Baird's conclusions as to the relative efficacy of

convergence and accommodation were really based upon the existence of pronounced *individual differences* in his data. Obviously, significant data of this sort could not have been anticipated.

2a. *Dissociation Due to Defective Accommodation.* Baird's conclusions are based upon the fact that one of his subjects, B, gave results which were different from those of his other subjects, and an ocular examination showed that this subject had defective accommodatory ability. Hence Baird's experiment is to be classed under the above rubric.

Baird assumed that all secondary criteria were excluded by his apparatus. This assumption might be seriously questioned, but we shall grant it for the purposes of this paper. It follows that accommodation and convergence are the only possible factors in the monocular judgments, while the additional factor of binocular parallax may be present in the binocular judgments.

We quote the following conclusions of Baird (3, p. 47):

"It has also been shown that in monocular vision—when the factors present are reduced to accommodation and convergence—the presence of normal accommodation has been attended by the capacity accurately to estimate relative distances, while the absence of normal accommodation has been paralleled by the absence of this capacity. From this we conclude that *accommodation constitutes the essential criterion of depth in our monocular experiments.*

"It follows from our binocular results that the essential criterion in the binocular experiments was not furnished by accommodation."

It may be noted that Baird does not specify the other factor operative in his binocular experiments. Obviously, it would need to be either convergence or binocular parallax.

The statement as to the efficiency of accommodation is stated in general terms, i.e., it is applicable to all subjects, and not limited to Subject B with defective accommodation.

Baird gives his tabular data for each of the five subjects and for each of his five experimental conditions; but he is nowhere clear and definite as to the precise data upon which his conclusions are based. Certainly not all of his comparative data are significant for his conclusions. We shall thus state and discuss the significance of the factual data of his tables.

1. Subject B's judgments in the monocular abrupt series were a

failure, but he exhibited normal accuracy in the monocular gradual series and in the monocular estimations of absolute distance.

Apparently, Baird assumed that this subject was unable to accommodate in the monocular abrupt series, but that he was able to do so in the other two conditions. On these assumptions, it might be concluded that monocular judgments of distance are based upon the factor of accommodation, while convergence is not effective. It may be noted, however, that this conclusion, based upon these data, is strictly applicable only to Subject B.

Another assumption is possible. The subject was unable to accommodate in the monocular abrupt series. Since accommodation and convergence are associated processes, we may make the additional assumption that convergent changes were also absent in this condition. Likewise, *both* accommodation and convergence were present *in the other two conditions*. On this assumption, monocular judgments of distance for Subject B are based upon accommodation and convergence, and no statement can be made as to their relative efficacy. We are not defending this assumption; we merely mention it as a possibility for consideration.

2. Subject B was unable to make any judgments of distance in the monocular abrupt series, but he exhibited normal accuracy in the binocular abrupt series.

This fact is apparently explained on the assumption that accommodation is absent in the first condition and present in the second, while convergence is present in both. Accommodation is thus regarded as the effective factor, while convergence has no effect. But again this conclusion can refer only to Subject B.

This conclusion ignores the further consideration that binocular parallax is absent in the first condition but is present in the second. This fact, taken by itself, is just as indicative of the functional efficacy of binocular parallax. When the fact is considered in conjunction with the previous data, it definitely supports the accommodatory hypothesis.

However, one can assume the absence of both accommodation and convergence in the monocular abrupt series. On this basis, both factors must be regarded as efficacious.

3. Subject B's binocular estimations of absolute distance were more accurate than his monocular estimates.

This fact is not commented on, but presumably the greater binocular accuracy is due to binocular parallax.

4. The comparative records of the normal subjects for the five conditions are obviously not significant for our purposes. These represent the standard type of data secured by Wundt, Hillebrand, and Dixon by the use of the classical method, and Baird has agreed that such data throw no light upon the problem of the relative efficacy of convergence and accommodation; rather they prove the efficacy of binocular parallax.

5. There remains for consideration only a comparison of the records of Subject B with those of the normal subjects for each of the five conditions.

Subject B was unable to make any judgments as to distance in the monocular abrupt series, but the normal subjects could. For all other conditions, Subject B compared favorably with the normal subjects. In only one condition was Subject B consistently the poorest subject of the group, and that was the case in which the subject was required to judge *the direction* of movement in the monocular gradual series.

Presumably these comparative data are to be explained in terms of the absence and presence of accommodation.

Two general comments may be made in regard to Baird's conclusions:

1. The conclusions are based primarily upon the inability of Subject B to make any judgments in the monocular abrupt series and the correlation of this fact with the assumed absence of accommodation under these conditions. One feels indisposed to settle the question upon such limited data. It is entirely possible that the relative influence of accommodation and convergence may vary with individuals. Certainly it is unwise to generalize on the basis of a single unique and inconsistent case.

2. Let us grant Baird's conclusion that accommodation is the most important factor in monocular judgments. We have been unable to find any empirical justification for his second conclusion that accommodation is not the most important factor in the binocular judgments.

2b. Voluntary Control of Accommodation. Another form of experimentation has involved the rather unusual ability of dissociating accommodation and convergence by voluntarily controlling accommodation. Several such cases have been described by Professor Carr (4, 5). A typical case is that of Miss Allen (6). This subject possesses a direct, voluntary control of accommodation independent

of the convergence. Depth is in her case a function of accommodation and is in no respect effectively influenced by changes in convergence.

Miss Allen observed two wires of identical size and appearance held in a vertical position and parallel to one another in a screw device a few inches in front of her eyes. She combined the foveal images of the two wires stereoscopically and then voluntarily controlled the depth location of the combined image by varying accommodation. Not only was Miss Allen able to observe changes in the apparent location of the combined image, but she perceived movement as well when the eyes were held in a fixed convergent position and accommodation voluntarily altered. Accommodation could also be held constant when convergence was altered by means of the screw device and the combined image was perceived constantly at some prescribed location.

The authors made no attempt to generalize on the basis of this single unusual case. The ability to voluntarily control accommodation in the manner described above is comparatively rare. Our problem concerns itself with the usual, normal functioning of accommodation and convergence in the perception of depth, and we are interested in special cases only in so far as they throw light on the wide variability among individuals with regard to the relative influence of the two factors.

2c. *Stereoscopic Dissociation.* A third method of dissociating accommodation and convergence is that of stereoscopic dissociation which falls into two classes, namely, "free" stereoscopy, represented by Le Conte (15) and Hyslop (10), and instrumental stereoscopy (13, 14).

1) *Free stereoscopy.* Hyslop possessed a high degree of proficiency in the art of free stereoscopy. He voluntarily converged in front of or behind the plane of two similar figures or objects, and binocularly combined the images of these objects. The lens failed to follow the convergent changes and remained accommodated for the actual distance of the object, for the two images were seen distinctly. The stereoscopic image was apparently located near the intersection of the visual axes rather than in the plane of accommodation. Depth was thus mainly a function of convergence rather than of accommodation. One cannot conclude that accommodation was not effective, nor can one make any exact quantitative statement as to their relative efficacy, except that convergence was much more effective. Secondary criteria were not excluded in these conditions,

and one does not know with certainty that the stereoscopic image was located exactly at the point of convergence rather than a short distance from it.

This case is the exact opposite of that of Miss Allen. For Hyslop, depth was mainly a function of convergence. For Miss Allen, depth is primarily a function of accommodation, the process which in her case possesses the most volitional importance. These cases represent opposite extremes, and we again note the probability that the relative influence of the two factors may be a wide individual variant. Both represent unusual cases from the standpoint of volitional dissociation and one must be cautious in generalizing from these to normal cases.

2) *Instrumental stereoscopy*. The mirror type of stereoscope is usually employed in these experiments. The two stereograms to be combined are placed at the ends of the two arms, and the light from these is reflected into the eyes by means of two small mirrors placed before the eyes. The stereoscopic image is then seen in front of the eyes at some distance beyond the mirrors.

Convergence can be altered in several ways: by rotating the two arms in relation to the mirrors, by changing the angle of the mirrors in relation to the eyes, by altering the distance between the two mirrors, and by moving the mirrors backward and forward in relation to the eyes. The stereoscopic image can be observed to move backward and forward with these induced changes of convergence. This experiment proves that convergence is a factor in the perception of distance, but one can make no definite quantitative statement as to its efficacy relative to that of accommodation for two reasons:

1. One does not know the exact location of the stereoscopic object in relation to the intersection of the visual axes. One does not know that the location of the stereoscopic object varies proportionally with convergence.

2. As Judd has pointed out (13, p. 388), all of these adjustments of the apparatus whereby convergence is altered also change to some extent the distance of the stereograms from the eyes. Consequently, accommodatory changes are involved as well as such secondary factors as intensity and size of the retinal image. Convergence is not altered with all other factors held constant. The perceptible change of distance may thus be due in part to these other factors.

Judd performed an experiment which is practically free from the second objection. In place of the stereograms, he used a star as the fixation object. He adjusted the mirrors so that the star was re

flected from both mirrors. By changing the angle of the mirrors to each other, the convergence was altered and the stereoscopic image of the star moved back and forth with the convergence. Any possible change of the distance between the eyes and the star was so small as to be negligible. For all practical purposes only convergence was altered, and these changes were quite effective upon the perception of distance.

The mirror stereoscope is still more defective in isolating accommodation. For this purpose it is customary to move the two stereograms along the arms nearer to or farther away from the mirrors and hence in relation to the eyes. The stereoscopic object may be observed to move backward and forward under these circumstances. Accommodation is altered in these adjustments while convergence is kept constant. However, one cannot conclude that the observed movement of the stereoscopic object is due to the accommodatory changes, for the size and intensity of the retinal stimulus is also altered proportionally. The ordinary mirror stereoscope involves insuperable defects so far as the isolation of accommodation is concerned.

In our experiments we employed a modified form of the mirror stereoscope which was so designed as to eliminate the defects we have noted in the usual form of the apparatus. Our stereoscope permits the alteration of either convergence or accommodation while keeping the other constant and without introducing any concomitant changes of any of the secondary criteria. The apparatus also involves a device which permits some quantitative statement of the location of the stereoscopic image in relation to the intersection of the optic axes and to the plane of accommodation. As previously noted, previous experiments with the stereoscopic method were defective in this respect.

APPARATUS

The apparatus we used was a new form of stereoscope designed and constructed under the direction of Professor Harvey Carr. A rough working model was first built and on the basis of this model the present stereoscope was perfected. It consists essentially of two brass telescopic tubes supported by a metal stand and fitted at the far ends with translucent screens of milk glass behind which are attached 2 $\frac{1}{2}$ -volt flashlight bulbs fed by dry batteries and controlled

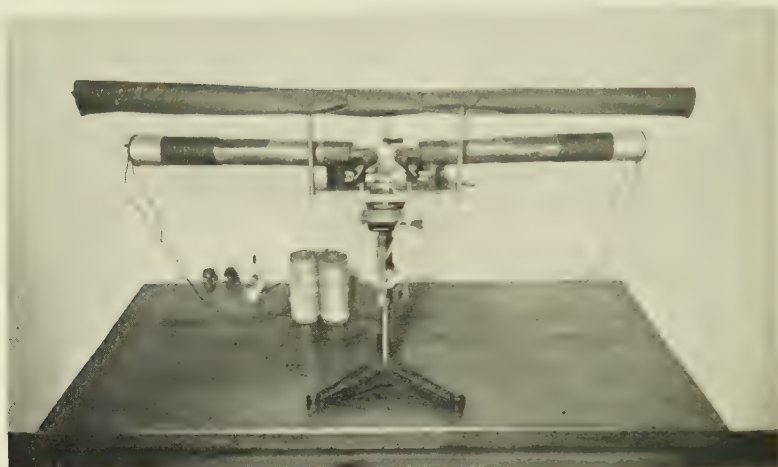


FIGURE 1

by rheostats. The tubes are bent at an angle of 88 degrees near the fixation ends and are fitted with mirrors at the angles so that when the subject is looking into the tubes the visible areas of the translucent screen at *A* and *A'* are seen as a single circular light at some point back of the mirrors in the plane of regard. (See Figure 1.) The mirrors are silvered on the front side rather than on the back to insure a perfect reflecting surface.

The control of convergence without altering the distance of the stereoscopic objects—the visible areas of the luminous screens—was accomplished in the following manner. Each telescopic tube was mounted upon a carriage which moved in a circular slot whose center coincided with the center of rotation of the corresponding eyeball when the head was in the proper observation position in the head-rest. By means of a knurled wheel (*B*) the telescopic tubes were moved in the circular slots (*C* and *C'*) and consequently the convergence of the eyes was altered. Since the tubes and the eyes have the same center of rotation, it is obvious that the distance between the eyes and the luminous screens must remain constant during these convergent rotations. With constant distance there can be no concomitant changes of accommodation or changes in the size and intensity of the retinal image.

A metal disc is located in each tube at the positions *D* and *D'*.

In the center of each disc is a small knife-edge opening $1/16$ of an inch in diameter. These openings are just large enough to permit an unobstructed view of the luminous screens when the eyes are in the proper position and the apparatus has been adjusted to the correct interocular distance. A small turnscrew at *E* makes this interocular adjustment possible. When the tubes are rotated, the luminous screens will continue to be visible if the centers of eye rotation coincide with the centers of rotation of the tubes. If the two centers of rotation differ to any marked extent, the presence of this small opening will prevent the subject from seeing the stereoscopic objects as whole and circular throughout the entire extent of convergent rotation. The ability of the subject to see the luminous circular object through the convergent adjustments thus indicates that the eyes have been properly adjusted to the apparatus.

Accommodatory changes were induced in the following manner. The distant ends of the tubes were of the telescopic or collapsible variety, and hence the distance of the stereoscopic objects—the luminous screens—from the eyes could be varied at will. Accommodation was thus altered without affecting the degree of convergence.

Concomitant changes in the size and intensity of the retinal images were excluded by the following device. A metal disc containing a knife-edge opening with a diameter of $7/16$ of an inch was located at *F* and *F'* in the figure. This size of opening did not permit a full view of the luminous screens even when the tubes were extended to their full length. The part of the tubes between *F* and *F'* and the eyes was not collapsible, and hence the distance between these openings and the eyes remains constant. As the luminous screens are moved toward the eyes, the surface area that is visible is decreased proportionally with the distance. In other words, the angular extent of the surface that is visible remains constant—that is, the retinal image does not vary in size.

Likewise, proportionally less light from the illuminated screens enters the eyes because less of the screens is visible. Consequently, the intensity of the retinal image likewise remains constant. The

formula is $I = \frac{kai}{d^2}$, where *I* is the total intensity, *k* is a constant,

a is the area, *i* the intensity per unit area, and *d* the distance from the eye to the source of light.

To keep the intensity of the retinal light constant as the distance

of the screens from the eyes is varied, reflected light from the sides of the tubes must not be permitted to enter the eyes. This was done in the usual way. The interior of the tubes was painted an optical black and a series of other metal discs with graduated openings were placed at intervals within the tubes between *D* and *F* and *D'* and *F'*.

The constancy of the intensity of the retinal light was easily tested in the following manner. The two tubes were so adjusted (by means of the knurled wheel *B*) that the binocular images were not combined. Consequently, the subject saw the two lights closely adjacent to each other. The two lights were adjusted by means of the rheostats until they were judged to be equal in intensity. The distance of one of the lights was then altered and the subject was again asked to judge their relative intensity. None of the subjects was able to detect any intensity changes in the altered light. The test proves that the intensity of the retinal light as judged by the subjects remains constant for all positions of accommodation.

The following method was employed to secure quantitative judgments as to the location of the stereoscopic object in relation to the plane of accommodation and the intersection of the visual axes. A brass rod 60 cm. in length projected straight back from the apparatus along the line of vision. It was calibrated in centimeters with the position of the eyes as the zero point of reference. To this was attached a movable pointer (*G*) which could be moved back and forth along the rod by means of a small wooden handle that could be conveniently grasped by the subject. The collapsible tubes were also calibrated in centimeters with the position of the eyes as the zero point of reference. The stereoscopic objects could thus be set at any desired distance from the eyes. The wheel (*B*) controlling the rotation of the tubes and the convergent status of the eyes was carefully calibrated by empirical means so as to indicate the distance of the intersection of the visual axes for the various adjustments. By means of these calibrations, the experimenter could easily and readily adjust either the accommodation or the convergence for any desired distance from the eyes.

Let us suppose that the accommodation is set for 25 cm. and the convergence for 40 cm. The subject then places his head in the required position and observes the stereoscopic image. He is then instructed to grasp the handle of the pointer and move it along the calibrated rod to the point where the visual object appears to be

located. The experimenter then records the position of the pointer in terms of its calibration which indicates the apparent distance of the visual object from the observer's eyes. If the reading were 36 cm., it would indicate that the subject perceived the stereoscopic object nearer to the point of convergence than to the plane of accommodation.

This motor method of measuring the apparent distance of a stereoscopic object was borrowed from Professor Ashley (2) who successfully employed a somewhat similar technique. Obviously, the accuracy and reliability of such a method cannot be judged on *a priori* grounds. Its validity can be tested only in terms of the accuracy and the reliability of the measures obtained with its use. As we shall see, the method furnished results of greater accuracy and reliability than one would expect.

The stereoscope was mounted on an adjustable upright bar, permitting the raising or lowering of the instrument to any desired height, with a heavy metal base firmly screwed to a substantial table. A three-way adjustable mouth-bit head-rest (*H*) attached to the upright bar insured steadiness of vision. A black curtain, leaving only the eye-holes and the head-rest visible to the subject, covered the entire apparatus.

PROCEDURE

In the first set of experiments five subjects were employed. Three were graduate students in psychology and two were undergraduates taking work in the Department. The subject seated himself before the instrument which was then raised or lowered to a convenient height. The tubes were set at the proper interocular distance and the head-rest adjusted so that when looking into the tubes the subject could steadily observe the single circular area of light, like a small white moon of low intensity, apparently some distance straight back along the line of vision. An intensity of light was so chosen, and kept as constant as possible throughout the experiments, that it would be clearly visible yet not too fatiguing to the eyes.

All the subjects knew in a general way that the experiment was designed to test accuracy of visual localization, but were ignorant of the mechanical nature of the apparatus. They were merely instructed to fixate the light and to move the marker, as accurately as possible, to the apparent location of the light back of the screen. Introspections

were called for from time to time in an attempt to throw some light upon the nature of the cues on which their judgments were based.

A number of preliminary judgments was made as a practice series to acquaint the subject with his task; but at no time during the preliminary practice or the entire experimental series was any indication of the accuracy or inaccuracy of his judgments given the subject.

Three positions of convergence and three corresponding positions of accommodation were arbitrarily selected as standards which, in combination, gave a total of nine conditions, namely: (1) accommodation and convergence both at 25 cm.; (2) accommodation and convergence at 30 cm.; (3) accommodation and convergence at 40 cm., the three conditions selected as standards; (4) accommodation at 30 cm., convergence at 25 cm.; (5) accommodation at 25 cm., convergence at 30 cm.; (6) accommodation at 30 cm., convergence at 40 cm.; (7) accommodation at 40 cm., convergence at 30 cm.; (8) accommodation at 25 cm., convergence at 40 cm.; and (9) accommodation at 40 cm., convergence at 25 cm.

The several conditions were presented in random order until 120 or more judgments had been recorded for each of the nine conditions, or a total of at least 1080 judgments for all conditions for each of the five subjects in the first set of experiments.

When the experiment was ready to proceed, a condition was selected and set by the experimenter. The subject then looked into the stereoscope, fixated the light, and moved the marker *out* as deliberately as he chose to its apparent location back of the screen. On the next judgment, for the same or a changed condition, the subject was required to move the marker *in* from a more distant point along the brass rod. Thus, for each subject, an equal number of out-going and in-coming judgments was recorded for each condition. On the whole, the former proved to be slightly more accurate. The shifts in the conditions were always made at a time when the subject was not observing the light. At the point where the subject reported the first signs of eye-strain the experiment was discontinued until the following or a later day. Usually not more than 15 or 20 judgments were made at a single sitting.

RESULTS AND CONCLUSIONS

Table 1 shows the means and standard deviations, based on 120 to 240 judgments in each condition, for the three standard conditions for each of the five subjects, and the average means for the sum total of judgments of all the subjects for the three standard conditions.

TABLE 1
MEANS AND SIGMAS OF STANDARD CONDITIONS EXPRESSED IN CENTIMETERS

Subjects	I		II		III	
	A 25	C 25	A 30	C 30	A 40	C 40
	Mean*		Mean		Mean	
A	24.62	1.52	29.78	2.00	39.50	1.79
B	25.33	1.16	30.28	1.43	39.48	1.59
C	24.04	1.53	29.90	1.84	40.36	1.75
D	25.05	1.35	29.89	2.01	39.87	1.59
E	24.14	1.38	29.72	2.05	39.83	1.74
All subjects	24.80		29.88		39.81	

*The mean values are based on 120 to 240 judgments.

All subjects showed a high degree of accuracy in their judgments in the standard conditions. The reader will recall that the subject is required to react motorly to what is apparently a single, undifferentiated circle of light "somewhere out there" before his eyes; that he has absolutely no other object in the visual field with which to relate the fixated light; and, further, that he must localize the light by means of an unseen movement.

It is evident from the data of Table 1 that the judgments of the distance of the stereoscopic object were extremely accurate. The deviations of the mean values from the true distance were always less than 1 cm. In the majority of cases the mean values were slightly less than the "true" distance. The judgments of any individual were relatively quite consistent. The sigma values for any group of judgments ranged from 1.16 to 2.05 cm.

These facts prove that the associated factors of convergence and accommodation are highly effective in mediating judgments of distance within the range of 25 to 40 cm. They also demonstrate the validity of our motor method of quantifying these judgments. It is a curious fact, but by no means new in experimental findings, that even in those occasional judgments where the subject reported a "lost" feeling, where he felt his judgments to be hardly more than mere guesses, there was usually little or no loss in accuracy. Our judgments are often based on unconscious cues; we react successfully, we know not how.

Table 2 shows the average judgments for all combinations of convergence and accommodation, including the three standard conditions separately shown in Table 1. The standard deviations are not in-

were called for from time to time in an attempt to throw some light upon the nature of the cues on which their judgments were based.

A number of preliminary judgments was made as a practice series to acquaint the subject with his task; but at no time during the preliminary practice or the entire experimental series was any indication of the accuracy or inaccuracy of his judgments given the subject.

Three positions of convergence and three corresponding positions of accommodation were arbitrarily selected as standards which, in combination, gave a total of nine conditions, namely: (1) accommodation and convergence both at 25 cm.; (2) accommodation and convergence at 30 cm.; (3) accommodation and convergence at 40 cm., the three conditions selected as standards; (4) accommodation at 30 cm., convergence at 25 cm.; (5) accommodation at 25 cm., convergence at 30 cm.; (6) accommodation at 30 cm., convergence at 40 cm., (7) accommodation at 40 cm., convergence at 30 cm.; (8) accommodation at 25 cm., convergence at 40 cm.; and (9) accommodation at 40 cm., convergence at 25 cm.

The several conditions were presented in random order until 120 or more judgments had been recorded for each of the nine conditions, or a total of at least 1080 judgments for all conditions for each of the five subjects in the first set of experiments.

When the experiment was ready to proceed, a condition was selected and set by the experimenter. The subject then looked into the stereoscope, fixated the light, and moved the marker *out* as deliberately as he chose to its apparent location back of the screen. On the next judgment, for the same or a changed condition, the subject was required to move the marker *in* from a more distant point along the brass rod. Thus, for each subject, an equal number of out-going and in-coming judgments was recorded for each condition. On the whole, the former proved to be slightly more accurate. The shifts in the conditions were always made at a time when the subject was not observing the light. At the point where the subject reported the first signs of eye-strain the experiment was discontinued until the following or a later day. Usually not more than 15 or 20 judgments were made at a single sitting.

RESULTS AND CONCLUSIONS

Table 1 shows the means and standard deviations, based on 120 to 240 judgments in each condition, for the three standard conditions for each of the five subjects, and the average means for the sum total of judgments of all the subjects for the three standard conditions.

centage values were derived from the data of Table 2 in the following manner: The mean value for Subject A was 24.62 cm. when accommodation and convergence were both set at 25 cm. The mean value was 29.78 cm. when the two were set at 30 cm. With convergence at 25 cm. and accommodation at 30 cm., the mean value was 26.91 cm. The difference between 26.91 and 29.78 is 2.87, and this value may be taken as a measure of the influence of convergence. Likewise, the difference between 26.91 and 24.62 is 2.29, and this is regarded as the measure of the influence of accommodation. The relative effectiveness of convergence and accommodation is thus expressed by the values of 2.87 and 2.29, respectively. All such values were then reduced to a common denominator by expressing them in percentage terms. The corresponding percentage values are 56 and 44, and these values are entered for Subject A, Condition IV, in Table 3.

An examination of Table 3 suggests the following conclusions:

1. The data of Table 3 again support our previous observation that both accommodation and convergence were effective in every case, for it will be noted that no zero values appear.
2. Convergence was always a more effective factor than accommodation as is evident from the fact that the percentage values for convergence are higher in every case. On the general average, convergence was found to be about three times as effective as accommodation in the judgment of distance within the limits of our experiment.
3. There is no conclusive evidence that the relative effectiveness of convergence and accommodation varies with individuals. The individual range of average values for convergence is from 72 to 79 per cent. However, the number of subjects was limited.
4. The relative effectiveness of the two factors varies with the degree of dissociation. When widely dissociated there is apparently a tendency to ignore accommodatory cues and place more reliance upon those of convergence.

EFFECT OF SIZE OF APERTURE

A very small aperture, e.g., a pin-hole, serves to give a clear image regardless of the degree of accommodation (9, 16). Such an aperture thus makes accommodatory changes unnecessary. In view of this fact, the question was raised as to whether the small size of the eye-holes used did not materially diminish the amount of accommo-

TABLE 3*
PERCENTAGES SHOWING RELATIVE INFLUENCE OF ACCOMMODATION AND
CONVERGENCE

Subjects	I			II			III			IV			V			VI			VII			VIII			IX			Aver-		
	A 25	A 30	C 40	A 25	A 30	C 40	A 25	A 30	C 40	A 25	A 30	C 40	A 25	A 30	C 40	A 25	A 30	C 40	A 25	A 30	C 40	A 25	A 30	C 40	A 25	A 30	C 40	A	C	A
A	44	56	12	88	17	83	23	77	15	85	23	77	15	85	23	77	22	78	13	87	22	78	22	78	22	78	22	78	22	78
B	31	69	43	57	33	67	23	77	23	77	23	77	22	78	13	87	27	73	11	89	28	72	21	79	21	79	21	79	21	79
C	40	60	42	58	36	64	20	80	20	80	20	80	20	80	20	80	20	80	20	80	20	80	20	80	20	80	20	80	20	80
D	15	85	14	86	39	61	20	80	20	80	20	80	20	80	20	80	20	80	20	80	20	80	20	80	20	80	20	80	20	80
E	42	58	18	82	49	51	11	89	18	82	27	73	18	82	27	73	18	82	27	73	18	82	27	73	18	82	27	73	18	82
Averages	34	66	26	74	35	65	19	81	19	81	19	81	19	81	19	81	19	81	19	81	19	81	19	81	19	81	19	81	19	81

*The first line indicates the various conditions of the experiment. The second line describes the several conditions, A 25 means that accommodation was set at 25 cm, C 25 means that convergence was set at 25 cm. The third line indicates the percentage of contribution that accommodation and convergence made to the actual judgments of the subjects. The following lines give these percentages.

TABLE 4*
PERCENTAGES SHOWING RELATIVE INFLUENCE OF ACCOMMODATION AND
CONVERGENCE
(Larger eye-hole)

Subjects	I			II			III			IV			V			VI			VII			VIII			IX			Average per- centages
	A 40	A 30	C	A 40	A 30	C	A 25	A 30	C	A 25	A 30	C	A 25	A 30	C	A 40	A 30	C	A 40	A 30	C	A 25	A 40	A 25	A 40	A 25	A 40	
C																												
F																												
G																												
H																												
Averages																												

*The first line indicates the various conditions of the experiment. The second line describes the several conditions. A 25 means that accommodation was set at 25 cm., etc. The third line indicates the percentage of contribution that accommodation and convergence made to the actual judgments of the subjects. The following lines give these percentages.

dation necessary for distinct vision, and hence minimize the relative influence of this factor.

To test this possibility, we increased the size of the eye-holes from 1/16 of an inch (the original size) to 5/16 of inch and repeated the experiment under otherwise similar conditions. This size of aperture exceeds the average size of the pupil in the normal, light-adapted eye. All observations were made under daylight conditions.

Four subjects were employed in this test which was conducted in the following year. Only one of these (Subject C) had also served in the first experiment. All the subjects in the test were graduate students in psychology.

Table 4 was derived in exactly the same manner as Table 3, and it presents the relative influence of convergence and accommodation, under the conditions of the larger eye-hole, in terms of percentages. On the basis of the comparative data of Tables 3 and 4 the following factual statements may be made:

1. The values for accommodation are larger in Table 4 for five of the six conditions for the group averages, but the differences are slight and probably are not statistically significant. However, the composition of the two groups is different with the exception of one subject.

2. Only one subject was employed in both experiments, namely, Subject C. In this case, the values for accommodation were slightly less for the larger opening, and the differences are not statistically significant.

There is thus no conclusive evidence that the effectiveness of accommodation increases with the size of the opening, and we may conclude that accommodation possesses only about one-third of the effectiveness of convergence for the distance limits which we investigated.

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L'INFLUENCE RELATIVE DE L'ACCOMMODATION ET DE LA CONVERGENCE DANS LE JUGEMENT DE LA DISTANCE

(Résumé)

Le but de cette étude a été d'évaluer, en termes quantitatifs, l'influence relative de l'accommodation et de la convergence dans le jugement de la distance. On a employé une nouvelle forme de stéréoscope à miroir au moyen duquel il a été possible de varier la convergence pendant que l'accommodation, la grandeur de l'image rétinale, l'intensité de l'objet stéréoscopique et tous les autres critères secondaires de la distance visuelle sont restés constants. On a pu aussi varier l'accommodation pendant que la convergence, l'intensité, etc., sont restées constantes. On a employé une méthode motrice pour mesurer la distance apparente de l'objet stéréoscopique. Quand la machine a été placée pour une des différentes combinaisons de convergence et d'accommodation (on a choisi arbitrairement neuf conditions, dont on a choisi trois comme contrôles), le sujet a fait mouvoir un indicateur d'un côté ou de l'autre sur un bâton de laiton étalonné à la position apparente de l'objet stéréoscopique. On a employé cinq sujets. Tous ont montré un haut degré de précision dans les trois conditions de contrôle. Les résultats dans

les conditions où la convergence et l'accommodation ont été désassociées ont suggéré les conclusions suivantes: (1) Que l'accommodation et la convergence toutes deux ont opéré dans tous les jugements; (2) Qu'en moyenne générale, la convergence a eu trois fois l'effet de l'accommodation dans les limites de l'expérience (c'est-à-dire, de 25 à 40 cm.); (3) Que nulles différences individuelles marquées n'ont été apparentes; (4) Que l'effet relatif des deux facteurs a varié avec le degré de désassociation.

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DIE RELATIVE EINWIRKUNG DER ANPASSUNG UND DER KONVERGENZ BEI DER BEURTEILUNG DER ENTFERNUNG

(Referat)

Es war das Ziel dieser Untersuchung, die relative Einwirkung der Anpassung der Konvergenz bei der Beurteilung der Entfernung quantitativ zu bewerten. Es wurde Gebrauch gemacht von einer neuen Form des Spiegelstereoskops (mirror stereoscope) mit dem es möglich war, die Konvergenz zu variieren während Anpassung, Grösse der Netzhautabbildung (retinal image), Intensität des stereoskopischen Gegenstandes, und alle übrige sekundäre unterscheidende Merkmale der visuellen Entfernung konstant gehalten wurden. Ebenfalls konnte die Anpassung variiert werden während Konvergenz, Intensität, u.s.w. konstant bleiben. Es wurde eine motorische Methode zur Messung der scheinbaren Entfernung des stereoskopischen Gegenstandes gebraucht. Wenn die Maschine für eine der verschiedenen Kombinationen von Konvergenz und Anpassung geregelt worden war (es wurden neun Zusammensetzungen willkürlich ausgewählt, von denen drei dann als Massstabe dienten) bewegte die Vp. einen Zeiger auswärts (oder nach innen) einen kalibrierten Stab aus Messing entlang, bis zur scheinbaren Lage des stereoskopischen Gegenstandes. Es wurden 5 Vpp. in Anspruch genommen. Alle erwiesen unter den drei massgebenden Gruppen von Umständen einen hohen Grad der Genauigkeit. Die Befunde unter den Umständen in denen Konvergenz und Anpassung dissoziiert waren, weisen auf folgende Schlüsse hin: (1) Dass sowohl Anpassung wie Konvergenz bei allen Urteilen wirksam waren; (2) dass, im allgemeinen Durchschnitt, die Konvergenz innerhalb der Grenzen des Versuchs (d.h., 25 bis 40 cm.) ungefähr drei Mal so stark wirkte wie die Anpassung; (3) dass sich keine ausgesprochene individuelle Unterschiede zeigten; (4) dass die relative Wirksamkeit der zwei Einwirkungen mit dem Grad der Dissoziation variierte.

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